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IMPROVEMENT OF THERMAL OPERATIONS OF GLASS-MELTING FURNACES

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The effect of thermal balance calculation for improvement of the efficiency of glass-melting furnaces is demonstrated.

The thermal operation of glass-melting furnaces can be studied by various methods, such as pyrometric, thermometric, balance, statistic, modeling, and other methods. Mathematical modeling of thermal processes in industrial furnaces is widely used at present [1 – 3]. The main advantages of mathematical models consist in their high precision and the large volume of information they generate. However, in the development of mathematical models for external heat exchange in high-temperature furnaces, the problem is complicated by the fact that the working space of a flame furnace is filled by radiating and absorbing gas components, whose optical parameters, temperature fields, and concentration field data are not available. It is necessary to take into account the heat released in fuel combustion and the convective heat transfer. All this limits the efficient use of mathematical models for studies and control of thermal operation of glass-melting furnaces.

Industrial glass production shows that one of the main methods for studying flame furnaces is the balance method which was used by A. I. Kukarkin and V. S. Kogo with respect to glass-melting furnaces [4].

We often encountered the situation where production companies, faced with the problem of developing a more perfect design for fuel-combustion equipment or developing the optimum thermal regime, categorically refused our suggestion for starting the work by preparing a thermal balance. The improvement of economical parameters is largely related to the improvement of the fuel combusted in furnaces, intensification of heat-exchange processes, development of more perfect fuel-burning equipment, etc.

In order to successfully solve all these questions, it is necessary first to have full knowledge of the specifics of thermal operations of a particular furnace design, its thermal engineering parameters, and design specifics, which can be obtained by means of balance investigations with subsequent analysis of the results and corresponding conclusions. An analysis of the thermal balance of a glass-melting furnace makes it possible to produce a justified evaluation of the degree of efficiency of the glass-melting furnace as a thermal aggregate, and in certain cases to determine ways for furnace reconstruction or means for improvement of its thermal regime.

However, transition to a different glass batch or fuel or wear of refractory materials frequently leads to technological problems related to the thermal operation of a particular glass-melting furnace. Production specialists usually try to solve these problems by varying the thermal load, which is most often accomplished by varying the level of fuel consumption. The determining factor for any thermal machine is the amount of heat absorbed by the processed material, and for glass-melting furnaces this parameter is the heat absorption of the fluid glass melt. If the tank receives less heat than the amount needed for the particular technological process, the glass quality is deteriorated and the thermal efficiency decreased. However, heat absorption depends not only on the thermal load, but also on the radiation parameters and length of the torch, the air consumption rate, the oxidizer heating temperature, etc.

In some cases, the share of heat absorbed by the melt as the result of external heat exchange in the furnace working space can be less that the share of heat directed to the lining. This primarily depends on the arrangement of the flame with respect to the melt and the brickwork, the size and shape of the flame, etc. Although it is a known fact that under a stationary heat regime the major part of the radiant flow directed to the lining is reflected, nevertheless an increase in the thermal load in such case always results in overheating of the lining. Moreover, if the flame has an insufficient degree of blackness, an increase in the amount of heat introduced into the furnace results in a noticeable increase in the heat loss through waste gases, which, in turn, is the reason for ex-

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cessive heating of the heat-exchange unit (a recuperator or regenerator).

In all cases, the correctly prepared thermal balance of a glass-melting furnace makes it possible to estimate the type and variation level of any parameter making part of the thermal balance equation. The use of the same method for measurement and calculation of individual parameters increases the reliability and comparability of the results and, as a consequence, makes it possible to use the obtained values and relationships not only for improvement of the thermal performance of the particular furnace but for the general analysis of similar furnace design.

It should be noted that thermal balances calculated for industrial furnaces can be direct or inverse. A direct heat balance is carried out to determine the share of each item in the general heat input or heat removal and to identify ineffective heat losses and determine ways and methods for their elimination. Moreover, based on a direct thermal balance, it is possible to assess the effect of various factors on the thermal performance of the furnace and determine it thermal efficiency. The calculation of the direct heat balance, as a rule, yields a residual between the input and output balance parts, which should not exceed 3 – 5% of the input heat. Such residual is accounted for not only by the relatively large error of measuring instruments and methods used in studies. The instruments and methods can be sufficiently precise and reliable, but as a consequence of methodic errors committed in the course of the measurement (a nonrepresentative measuring point, absence of protection from collateral effects, infiltration of ambient air, etc.), the resulting data used in the balance calculation lead to significant errors.

An inverse thermal balance is calculated to determine some of the most essential balance items which are impossible or very hard to measure directly. They are considered as the residual member of the thermal balance equation. Usually this parameter is heat absorption, i.e., the amount of heat absorbed by the batch or melt per time unit. The possibilities of direct measurement of heat absorption is rather limited due to the imperfection of the measurement tools. Usually this is done via thermal probes or various designs of heat meters for measuring heat flows. In this way the direct and reverse heat flows are determined, and heat assimilation is found from this difference.

Unfortunately, not every furnace contains the necessary quantity of holes in its walls through which thermal probes can be introduced into the working space. A limited number of measurements in combination with the substantial nonuniformity of the heat flows with respect to the length and width of the working space can result in a substantial error in determining the average value of heat absorption for the whole surface of the batch. However, the most efficient way of studying an industrial furnace is the combination of thermometric and balance methods which complement each other and make it possible to obtain more precise results [5].

Since a heat balance is a particular case of the law of conservation of energy, it helps to reveal the concealed heat losses which make the furnace performance unsatisfactory. For example, the authors in [6, 7] implemented an improved heating system designed by them on two similar recuperative furnaces with the double roof. A complex of measures including a new burner unit, rational distribution of the fuel between the gas burners, and the intensification of heat exchange processes made it possible to increase the specific glass melt output to 530 kg/m^2 per day and thus increase the furnace efficiency by 5.1%, whereas the specific fuel consumption decreased by 12.3%. However, although all technological and thermal mode parameters in both furnaces were maintained within a preset interval, the resulting glass balls on one of the furnaces all had the top grade quality, whereas the glass balls produced in the second furnace were of a lower grade with unstable quality. Due to the poor working characteristics of the latter, part of the product was rejected as waste.

TABLE 1

Parameter	Furnace A	Furnace B
Input items		
Fuel heat, %:		
chemical	79.26	75.75
physical	20.74	24.25
Consumption items		
Loss through heat conduction, %:		
via brickwork	2.88	3.12
via the bottom	4.50	4.38
Heat loss, %		
with waste gases	42.89	47.10
with evaporation heating	23.70	22.47
with radiation through holes	0.01	0.01
through batch heating and glass-melting processes	26.02	22.92

We calculated the inverse thermal balances for both furnaces (Table 1). For convenience reasons, instead of the absolute values (in kW) for each item, the relative share of this item in the total heat input or heat removal is indicated (in %).

It can be seen from Table 1 that the share of heat consumed in glass melting in furnace B, which is calculated as the residual term of the thermal balance, is 3.1% lower than in furnace A. At the same time, the heat losses with the waste gases are 4.21% higher. Based on the analysis of the balance studies, it was proposed to increase the thermal load in furnace B and, by means of development of a lower-angle flare, to increase the amount of the heat transmitted to the glass melt. As a consequence of these measures, furnace B ceased generating defective products, and its thermal performance improved significantly, which was confirmed by subsequent balance studies. The share of heat spent on glass melting grew to 28.2%, and the heat loss through the waste gases decreased to 39.84%.

Let us discuss another example of using balance studies to justify the reconstruction of a furnace with evaporative cooling of the tank. There are various methods for chilling certain parts of the brickwork in order to extend its service

TABLE 2

Parameter	Furnace A	Furnace B
Input items		
Fuel heat, %:		
chemical	75.05	75.07
physical	24.95	24.93
Consumption items		
Loss through heat conduction via gas space lining, %	5.68	9.09
Heat loss, %:		
with waste gases	38.34	38.26
with evaporation heating of tank	26.52	-
via tank wall brickwork (instead of ECS)	-	4.92
through heat conduction via tank walls	4.11	6.62
with radiation through holes	0.03	0.06
through batch heating and glass-melting processes	25.51	41.04

life. As the brickwork temperature decreases, a slag layer of molten glass is formed on the inner surface of the brickwork, or low-mobility fluid glass masses emerge, which protect the refractory lining from intense corrosion.

Virtually all systems used for chilling of the glass-melting furnace lining do not provide for utilization of released heat. The only exception is the evaporative cooling system (ECS) implemented in 1970 for chilling the lateral tank walls [8]. The ECS made it possible to double the furnace life cycle compared with a similar furnace with external air cooling; furthermore, the ECS additionally generated up to 22 tons of overheated steam to the steam supply system of the factory. Moreover, a furnace with evaporation heating is able to operate under a more intense thermal mode. However, it should be noted that the limited increase in the convective heat transfer to the melt carried out by direct flame radiation was accomplished at the expense of significant technological difficulties and did not result in an expected intensification of the melting processes, since a substantial part of the absorbed heat (up to 50% of the assimilated amount) was lost through evaporative heating.

At the same time, Russian and foreign glass manufacturers in the last decade successfully use chromium-oxide refractories containing up to 94% Cr_2O_3 and 4% TiO_2, which have an exceptionally high degree of resistance to glass, especially to aluminum-boron-silicate glasses, 5 – 10 times higher than any of other known refractories. For reference purpose, we analyzed the balance in order to compare the main technical and economic parameters of the same furnace design (Table 2) in two variants: a furnace with evaporation cooling of the tank walls (A) and a furnace made of chromium-oxide refractories which do not require additional cooling (B).

The thermal balance for the first variant was obtained by direct measurement of the existing furnace, and the second variant of the balance (variant B) was calculated. All data used in the calculation (waste gas temperature, air heating temperature, air consumption coefficient, etc.) were left unchanged, which obviously introduced a certain error. Therefore, the heat balance data in Table 2 can give only an approximate estimation of the effect of conversion to the new design.

Based on the obtained results, we carried out an estimated calculation of the replacement of ECS by chromium-oxide refractories and fuel saving by reducing heat losses via the tank walls. Even such approximate calculations corroborated the expediency of converting the evaporation-cooled tank furnace to the design using chromium-oxide refractories. In this case, the specific fuel consumption per ton of finished glass balls is expected to decrease by 20%, the expected increase in efficiency can amount to 18%, and the expected period of investment repayment does not exceed 3 months.

Thus, the thermal balance of glass-melting furnaces is now one of the most efficient and reliable methods for studying their thermal operation. Balance studies make it possible not only to obtain a full understanding of the thermal engineering state of a particular furnace but, if necessary, to determine the direction for furnace reconstruction or improvement of the thermal mode.

Thermal balance data can be the basis for subsequent analytical study of the thermal performance of glass-melting furnaces using mathematical models for external heat exchange inside the gas space of these furnaces.

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